Platform for On-Board Real-Time Detection of Wet, Icy and Snowy Roads, using Tyre/Road Noise Analysis

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***Abstract*—In this paper, a new approach capable of detecting water, ice and snow on the road surface is shown, focusing on the hardware needed for the practical implementation. Proposed platform uses a simple microphone and a general purpose microcontroller. The system is tightly integrated with vehicle ECUs (Electronic Control Units). A CAN bus allows it to read some of the variable dynamics provided by the sensors already installed in virtually every motor vehicle. Detector results are also published through the CAN bus to be displayed on the vehicle console and to be used by other ECUs. Proposed system is simple, cheap and easy to install. Initial tests for the wet/dry detector classes have shown a very high success rate.**

Keywords—Road safety; Road surface state; Tyre/road noise, Support Vector Machines, Intelligent transportation systems

I. Introduction

A frequent cause of road accidents is the presence of water, ice or snow on the asphalt. A driver traversing a wet, icy or snowy road must adapt his driving style accordingly, reducing the speed and increasing alertness. Even a cautious and experienced driver can be involved in an accident due to the presence of *black ice* or deep water formations in localized areas. Also the psychological *anchoring effect* [1] can make really difficult for a driver to notice adverse changes in weather while travelling.

Informing the driver in real time about the presence of water, ice and snow on the road could lead to a great improvement in driving safety. This information could also be used to improve the response of other electronic traction control systems.

Weather road status detection has been addressed with different approaches [2][3]. Unfortunately none of them combines a high success rate, low cost, real time operation and small size (to allow it to be embedded in a motor vehicle). The system proposed in this paper is based on the analysis of the tyre/road noise of the vehicle, in a similar way as the one introduced by Kongrattanaprasert [4] but with some important differences: it is designed to be installed on-board, and uses a classifier based on SVM (Support Vector Machines).

II. System Operation

Tyre/road noise is usually the greatest noise source when driving at legal speeds greater than 40 km/h. Although generated tyre/road noise depends on many variables, the acoustic footprint of a tyre rolling on dry asphalt is easily distinguishable of the one generated by a tyre rolling on wet asphalt [5]. Tyre/road noise generated on icy and snowy roads is also different [4]. It is thus possible to estimate the presence of water, ice and snow on the road by analyzing the tyre/road noise generated during driving.

Proposed system architecture is shown in Fig. 1. Radiated tyre/road noise signal is captured with a microphone. A *Signal conditioning* block amplifies the captured signal. Then the *A/D conversion* block translates the signal to a collection of digital samples. The *Feature extraction* block, extracts the relevant frequency components of the signal, and outputs the feature vector to the *SVM classifier* block. The SVM classifier will output the road state estimation based on each of the obtained feature vectors, and on the data from the pre-computed *Support vectors*. Output from the *SVM classifier* block can be directly

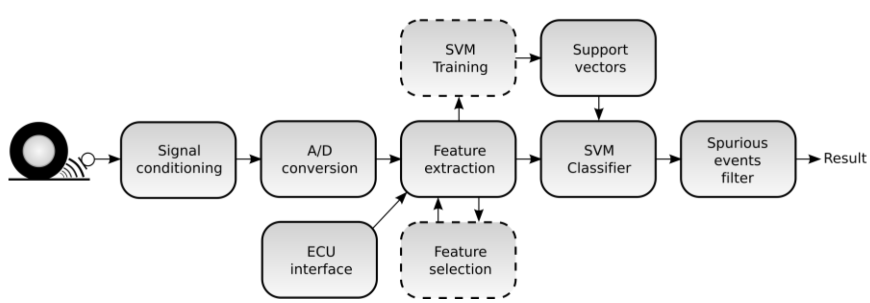

Fig. 1. System blocks

used, but to improve the estimation performance, an additional *Spurious events filter* block is recommended, to suppress wrong classifications due to spurious events.

The *ECU interface* allows to obtain the vehicle speed and engine RPM, and also to write the estimation results, so they can be shown in the vehicle console, and used by other ECUs. Blocks shown in dashed lines in Fig. 1, are only needed during the training stage, and are not needed in the final system.

A preliminary implementation of the proposed system (lacking the ECU interface), has already been field-tested, achieving success rates as high as 100 % for dry to wet transitions, and 91 % for wet to dry transitions. Obtained response times are about 0.2 s for the dry to wet transitions [6].

III. PLATFORM ARCHITECTURE

The proposed hardware blocks needed to implement the system described in Fig. 1, are shown in Fig. 2.

A. System core

To enhance system integration and reduce component count, a microcontroller has been used to implement the system core. LM4F120H5QR microcontroller from *Texas Instruments* was chosen because it has more than enough computing power to implement the required tasks. This microcontroller is powered by an ARM Cortex-M4F core, and includes almost all the peripherals needed by the system.

B. Microphone

Tyre/road noise signal is captured using a microphone. One of the advantages of using supervised learning algorithms for the classifier is that it allows to relax the linearity and frequency response requirements of the microphone. The microphone does neither need a wide dynamic range. Careful placement of the microphone guarantees it will receive high sound pressure levels, easily above 70 dB when driving at speeds higher than 50 km/h. A cheap electret microphone can easily meet the requirements needed by the system. The practical implementation of the system, uses a WM63-PRT electret microphone from *Panasonic*.

C. Signal conditioning

The weak signal output by the microphone is amplified and band-pass filtered before it is applied to the analog to digital converter (ADC). Signals below 7 Hz are filtered out to suppress DC offset, and to reduce very low frequency noise usually present in microphones. This stage is also configured to meet the ADC requirements.

D. Analog to Digital Converter

The ADC chosen is a CS5361 from *Cirrus Logic*. To reduce the CPU power required by the classifier, it is recommended to use the lowest possible sampling frequency. As the upper frequency component needed by the classifier is the 5 kHz one, the sampling frequency must be above 10 kHz. To ease the implementation of the 1/3 octave filters, a frequency value that is a power of two is preferred. So a 16384 Hz sampling frequency was chosen.

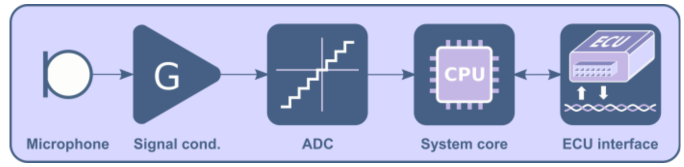

Fig. 2. Hardware blocks comprising the system

E. Electronic Control Unit interface

To implement the ECU interface, an ELM327 OBD to RS232 interpreter from *ELM Electronics* has been used. As the LM4F120H5QR microcontroller integrates two internal CAN interfaces, the ELM327 integrated circuit may be removed in the future.

F. Power considerations

To keep the component count low, and reduce power consumption, the power stage has been designed avoiding symmetric power source configurations. This has been accomplished by doing a careful analog design, and using rail-to-rail operational amplifiers.

IV. RESULTS AND DISCUSSION

Proposed hardware platform is capable of implementing the road surface status detector using low cost components, without the need of using specialized elements, such as Digital Signal Processors (DSP), high performance condenser microphones, etc. Preliminary tests have shown that the signal processing and classifier algorithms fit inside the chosen microcontroller, using only 5.3 % of its CPU power, 14.9 % of its internal Flash memory and 22.3 % of its RAM. The available resources will allow to use an even cheaper microcontroller and to remove the external ECU interface (the ELM327 integrated circuit), implementing it inside the microcontroller. Developed prototype works in real time, and is low power and small (around 7 cm x 7 cm), allowing it to be integrated in a motor vehicle.

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